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Hydropower for sustainable water and energy development

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ABSTRACT

Turkey has a total gross hydropower potential of 433 GWh/year, but only 125 GWh/year of the total hydroelectric potential of Turkey can be economically used. By the commissioning of new hydropower plants, which are under construction, 36% of the economically usable potential of the country would be tapped. Turkey presently has considerable renewable energy sources. The most important renewable sources are hydropower, biomass, geothermal, solar and wind. Turkey's geographical location has several advantages for extensive use of most of these renewable energy sources. Over the last two decades, global electricity production has more than doubled and electricity demand is rising rapidly around the world as economic development spreads to emerging economies. Not only has electricity demand increased significantly, it is the fastest growing end-use of energy. Therefore, technical, economic and environmental benefits of hydroelectric power make it an important contributor to the future world energy mix, particularly in the developing countries.

Contents

1. Introduction

Energy is considered a prime agent in the generation of wealth and also a significant factor in economic development. The importance of energy in economic development has been recognized almost universally. The historical data attest to a strong relationship between the availability of energy and economic activity. During the past two decades, the risk and reality of environmental degradation have become more apparent. Growing evidence of environmental problems is due to a combination of several factors, since the environmental impact of human activities has grown dramatically because of the sheer increase of world population, consumption, industrial activity, etc. Achieving solutions to the environmental problems we face today requires long-term potential actions for sustainable development. In this regard, renewable energy resources appear to be one of the most efficient and effective solutions. That is why there is an intimate connection between renewable energy and sustainable development [1–3].

Hydropower is available in a broad range of project scales and types. Projects can be designed to suit particular needs and specific site conditions. As hydropower does not consume or pollute the water it uses to generate power, it leaves this vital resource available for other uses. At the same time, the revenues generated through electricity sales can finance other infrastructure essential for human welfare. This can include drinking water supply systems, irrigation schemes for food production, infrastructures enhancing navigation, recreational facilities and ecotourism.

Water is a vital resource that supports all forms of life on earth. Unfortunately, it is not evenly distributed by season or geographical region. Some parts of the world are prone to drought, making water a particularly scarce and precious commodity. In other parts of the world, floods that cause loss of life and property

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Table 1
Advantages and disadvantages of the hydropower option.

Advantages	Disadvantages
Economic aspects	
Provides low operating and maintenance costs	High upfront investment
Provides long life span (50–100 years and more)	Precipitation
Provides reliable service	Requires long-term planning
Includes proven technology	Requires long-term agreements
Instigates and fosters regional development	Requires multidisciplinary involvement
Provides highest energy efficiency rate	Often requires foreign contractors and funding
Creates employment opportunities and saves fuel	
Social aspects	
Leaves water available for other uses	May involve resettlement
Often provides flood protection	May restrict navigation
May enhance navigation conditions	Local land use patterns will be modified
Often enhances recreation	Waterborne disease vectors may need to be checked
Enhances accessibility of the territory and its resources	Requires management of competing water uses
Improves living conditions	
Sustains livelihoods (fresh water, food supply)	
Environmental aspects	
Produces no pollutants but only very few GHG emiss.	Inundation of terrestrial habitat
Enhances air quality	Modification of hydrological regimes
Produces no waste	Modification of aquatic habitats
Avoids depleting non-renewable fuel resources	Water quality needs to be managed
Often creates new freshwater ecosystems with increased productivity	Temporary introduction of methylmercury into the food chain needs to be monitored/managed
Enhances knowledge and improves management of valued species due to study results	Species activities and populations need to be monitored
Helps to slow down climate change	Barriers for fish migration, fish entrainment
Neither consumes nor pollutes the water it uses for electricity generation purposes	Sediment composition and transport may need to be monitored/managed

Source: Ref. [3].

are major problems. Throughout history, dams and reservoirs have been used successfully in collecting, storing and managing water needed to sustain civilization. Hydropower often supports other essential water services such as irrigation, flood control and drinking water supplies. It facilitates the equitable sharing of a common vital resource. Table 1 shows the advantages and disadvantages of the hydropower option [4–7].

With an estimated 95% of population growth in the coming decades likely to be in and around cities, the need for sustainable solutions with compact, interconnected power plants will be ever more pressing. Decentralized schemes, however, will remain important for rural electrification programmes. Hydropower can be adaptive and flexible. Depending on the storage capacity involved, a major advantage of hydropower is that generation can be scheduled. Run-of-river schemes can be implemented to provide continuous 'base-load' generation. The operation of a cascade of several run-of-river power plants can be optimized to provide generation when it is needed. This is especially true if there is a reservoir scheme at the head of the cascade. Schemes that include a reservoir are able to store potential energy for production when the demand is highest. When water resources are not available to replenish reservoirs by natural inflow, pumped-storage schemes have been developed to assist in the storage of energy from other generation sources. Therefore, hydropower can substantially improve efficiency in a mixed power system, reducing emissions from fossil fuel power plants, and backing up intermittent sources such as wind power [4,8,9].

Urban water systems play an important role in sustainable development in that they meet a fundamental need of people: access to drinking water and sanitation. In the immediate future, it is extremely important that these services become available to all people [4]. From a longer term perspective, it is equally important how these services are made available, so that they can be sustained for future generations. At present, the urban water systems of the industrialized world most often do not function well: though they do deliver the services they were meant to, i.e. drinking water and sanitation, they are not necessarily sustainable. For one thing, they consume resources [10,11].

They directly consume resources such as energy, chemicals, and water, but are also involved in indirect consumption, as the recycling of soil conditioners and nutrients, notably phosphorus, is either hindered by the presence of pollutants or accompanied by emissions of them. Water-soluble substances, on the other hand, including certain nutrients and pollutants, are not efficiently captured by sewage-treatment plants, but largely pass through to receiving waters. Both steadily growing urban populations around the globe and rising environmental awareness are increasing the pressure for society to come to grip with these problems and work towards the sustainability of urban water systems. This is particularly important considering the large parts of the developing world where urban water systems are not yet developed, but desperately needed [11].

The concept of sustainable development as used today dates back to the early 1980s. Of all the definitions proposed since then, the definition formulated by the World Commission on Environment and Development (WCED) in their report, Our Common Future, also known as the ''Brundtland report'', still seems to be the most widely known and accepted: ''Development that meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations'' [12]. Following the U.N. conference on Environment and Development in Rio de Janeiro in 1992, the concept became globally recognized, and the nearly 180 participating countries agreed on a plan of action, ''Agenda 21''. With the acceptance of the concept (although variously interpreted) and of Agenda 21, came the need to measure various aspects of sustainable development. This brought sustainable development indicators (SDIs) into focus. Several research initiatives examining SDIs have resulted in frameworks for organizing suggested indicators [13,14] while other initiatives have produced methods, most often emphasizing stakeholder participation, for selecting or constructing indicators [15,16]. In both cases, more or less a lengthy list of SDIs has been

the result. There are, however, few examples of successful SDI implementation.

In water utilities whether private or public, there is a general and long-standing tradition of using indicators in monitoring and reporting environmental performance [17]. Drinking water quality needs to be monitored to safeguard public health, and effluents from wastewater treatment plants need to be monitored to safeguard human and environmental health. In the water sector there are many examples of performance indicators that also convey information relating to sustainable development in a broad sense. Some of these can be termed SDIs, and capture, for example, management, health, environmental, and financial aspects of water operations [18–22]. Thus, many SDIs are used in the water sector, but as with all tools, their effectiveness depends on how they are applied. Such indicators are primarily used in performance monitoring and reporting to permitting authorities; as well, benchmarking is a relatively frequent and increasingly used indicator application in the water industry, although making comparisons between organizations remains difficult. Other potential applications include planning and reporting to a wider audience. Such applications are presumably just as important in supporting sustainable development, but there are few or no documented examples of them in the water sector [11].

2. Energy consumption and climate change in the world and in Turkey

Annual total greenhouse gas (GHG) emissions arising from the global energy supply sector continue to increase. Combustion of fossil fuels continues to dominate a global energy market that is striving to meet the ever-increasing demand for heat, electricity and transport fuels. GHG emissions from fossil fuels have increased each year since the IPCC 2001 Third Assessment Report (TAR) [23], despite greater deployment of low- and zero-carbon technologies such as renewable energy sources; the implementation of various policy support mechanisms by many states and countries; the advent of carbon trading in some regions, and a substantial increase in world energy commodity prices. Without the near-term introduction of supportive and effective policy actions by governments, energy-related GHG emissions, mainly from fossil fuel combustion, are projected to rise by over 50% from 26.1 $GtCO_2$eq (7.1 GtC) in 2004 to 37–40 $GtCO_2$ (10.1–10.9 GtC) by 2030. Mitigation has therefore become even more challenging [24].

Global dependence on fossil fuels has led to the release of over 1100 $GtCO_2$ into the atmosphere since the mid-19th century. Currently, energy-related GHG emissions, mainly from fossil fuel combustion for heat supply, electricity generation and transport, account for around 70% of total emissions including carbon dioxide, methane and some traces of nitrous oxide. To continue to extract and combust the world's rich endowment of oil, coal, peat, and natural gas at current or increasing rates, and so release more of the stored carbon into the atmosphere, is no longer environmentally sustainable, unless carbon dioxide capture and storage (CCS) technologies currently being developed can be widely deployed [24].

There are regional and societal variations in the demand for energy services. The highest per-capita demand is by those living in Organization for Economic Co-operation and Development (OECD) economies, but currently, the most rapid growth is in many developing countries. Energy access, equity and sustainable development are compromised by higher and rapidly fluctuating prices for oil and gas. These factors may increase incentives to deploy carbon-free and low-carbon energy technologies, but conversely, could also encourage the market uptake of coal and cheaper unconventional hydrocarbons and technologies with consequent increases in carbon dioxide (CO_2) emissions [25].

Energy access for all will require making available basic and affordable energy services using a range of energy resources and innovative conversion technologies while minimizing GHG emissions, adverse effects on human health, and other local and regional environmental impacts. To accomplish this would require governments, the global energy industry and society as a whole to collaborate on an unprecedented scale. The method used to achieve optimum integration of heating, cooling, electricity and transport fuel provision with more efficient energy systems will vary with the region, local growth rate of energy demand, existing infrastructure and by identifying all the co-benefits [25].

The wide range of energy sources and carriers that provide energy services need to offer long-term security of supply, be affordable and have minimal impact on the environment. However, these three government goals often compete. There are sufficient reserves of most types of energy resources to last at least several decades at current rates of use when using technologies with high energy-conversion efficient designs. How best to use these resources in an environmentally acceptable manner while providing for the needs of growing populations and developing economies is a great challenge [24–28].

Security of energy supply issues and perceived future benefits from strategic investments may not necessarily encourage the greater uptake of lower carbon-emitting technologies. The various concerns about the future security of conventional oil, gas and electricity supplies could aid the transition to more low-carbon technologies such as nuclear, and renewables. However, these same concerns could also encourage the greater uptake of unconventional oil and gaseous fuels as well as increase demand for coal and lignite in countries with abundant national supplies and seeking national energy supply security [27].

Addressing environmental impacts usually depends on the introduction of regulations and tax incentives rather than relying on market mechanisms. Large-scale energy-conversion plants with a life of 30–100 years give a slow rate of turnover of around 1–3% per year [22]. Thus, decisions taken today that support the deployment of carbon-emitting technologies, especially in countries seeking supply security to provide sustainable development paths, could have profound effects on GHG emissions for the next several decades. Smaller scale, distributed energy plants using local energy resources and low or zero-carbon-emitting technologies, can give added reliability, be built more quickly and be efficient by utilizing both heat and power outputs locally. On the other hand, more energy-efficient technologies can also improve supply security by reducing future energy supply demands and any associated GHG emissions. However, the present adoption path for these, together with low- and zero-carbon supply technologies, as shown by business-as-usual baseline scenarios, will not reduce emissions significantly [23,24].

The transition from surplus fossil fuel resources to constrained gas and oil carriers, and subsequently to new energy supply and conversion technologies, has begun. However it faces regulatory and acceptance barriers to rapid implementation and market competition alone may not lead to reduced GHG emissions. The energy systems of many nations are evolving from their historic dependence on fossil fuels in response to the climate change threat, market failure of the supply chain, and increasing reliance on global energy markets, thereby necessitating the wiser use of energy in all sectors. A rapid transition toward new energy supply systems with reduced carbon intensity needs to be managed to minimize economic, social and technological risks and to co-opt those stakeholders who retain strong interests in maintaining the status quo. The electricity, building and industry sectors are beginning to become more proactive and help governments make the transition happen. Sustainable energy systems emerging as a result of government, business and private interactions should not

be selected on cost and GHG mitigation potential alone but also on their other co-benefits [25].

Innovative supply-side technologies, on becoming fully commercial, may enhance access to clean energy, improve energy security and promote environmental protection at local, regional and global levels. They include thermal power plant designs based on gasification; combined cycle and supercritical boilers using natural gas as a bridging fuel; the further development and uptake of renewable energy systems; and advanced nuclear technologies. More efficient energy supply technologies such as these are best combined with improved end-use efficiency technologies to give a closer matching of energy supply with demand in order to reduce both losses and GHG emissions [26–28].

Energy services are fundamental to achieving sustainable development. In many developing countries, provision of adequate, affordable and reliable energy services has been insufficient to reduce poverty and improve standards of living. To provide such energy services for everyone in an environmentally sound way will require major investments in the energy supply chain, conversion technologies and infrastructure, particularly in rural areas of all developing countries [12,13].

There is no single economic technical solution to reduce GHG emissions from the energy sector. There is however good mitigation potential available based on several zero- or low-carbon commercial options ready for increased deployment at costs below 20 US\$/tCO_2 avoided or under research development. The future choice of supply technologies will depend on the timing of successful developments for advanced nuclear, advanced coal and gas, and second-generation renewable energy technologies [27]. Other technologies, such as biofuels, concentrated solar power, ocean energy and biomass gasification, may make additional contributions in due course. The necessary transition will involve more sustained public and private investment in research, development, demonstration and deployment to better understand our energy resources, to further develop cost-effective, efficient and low- or zero-carbon-emitting technologies, and to encourage their rapid deployment and diffusion. Research investment in energy has varied greatly from country to country, but in most cases has declined significantly in recent years since the levels achieved soon after the oil shocks during the 1970s, 1980s and 2000s for high prices [28].

No single policy instrument will ensure the desired transition to a future secure and decarbonized world. Policies will need to be regionally specific and both energy and non-energy co-benefits should be taken into account. Internalizing environmental costs requires development of policy initiatives, long-term vision and leadership based on sound science and economic analysis. Effective policies supporting energy supply technology development and deployment are crucial to the uptake of low-carbon emission systems and should be regionally specific. A range of policies is already in place to encourage the development and deployment of low-carbon-emitting technologies in OECD countries as well as in non-OECD countries including Brazil, Mexico, China and India. Policies in several countries have resulted in the successful implementation of renewable energy systems to give proven benefits linked with energy access, distributed energy, health, equity and sustainable development. Nuclear energy policies are also receiving renewed attention. However, the consumption of fossil fuels, at times heavily subsidized by governments, will remain dominant in all regions to meet ever-increasing energy demands unless future policies take into account the full costs of environmental, climate change and health issues resulting from their use [13,23,27].

In 2005, primary energy production and consumption has reached 28 and 94.3 million tons of oil equivalents (Mtoe) respectively (Tables 2 and 3). The most significant developments in production are observed in coal production, hydropower, geothermal, and solar energy. Turkey's use of hydropower, geothermal and solar thermal energy has increased since 1990. However, the total share of renewable energy sources in total primary energy supply (TPES) has declined, owing to the declining use of non-commercial biomass and the growing role of natural gas in the system. Turkey has recently announced that it will reopen its nuclear programme in order to respond to the growing electricity demand while avoiding increasing dependence on energy imports [29–31].

Table 2
Selected indicators of primary energy consumption and resources (thousands TOE) in Turkey.

	2005 realization		2006 estimate		2007 estimate	
	Amount	(%)	Amount	(%)	Amount	(%)
Commercial energy	89,050	94.4	93,680	94.7	96,680	94.5
Hard coal	14,805	15.7	15,052	15.2	16,052	15.2
Lignite	10,760	11.4	11,005	11.1	12,005	11.1
Petroleum products	32,855	34.8	35,160	35.6	37,160	35.6
Natural gas	25,665	27.2	27,356	27.7	29,356	27.7
Hydraulic energy	3744	4.0	3801	3.8	3981	3.8
Renewable energy	1350	1.4	1427	1.4	1627	1.4
Non-commercial energy	5250	5.6	5200	5.3	56,080	5.5
Wood	4100	4.4	4100	4.1	4100	4.1
Biomass	1150	1.2	1100	1.1	1100	1.4
Total	94,300	100	98,880	100	102,288	100
Consumption per-capita (KEP)	1249		1291		1337	

TOE: Tons of oil equivalent; KEP: kilogram of oil equivalent.
Source: Ref. [29].

Energy sector reform is critical to sustainable energy development and includes reviewing and reforming subsidies, establishing credible regulatory frameworks, developing policy environments through regulatory interventions, and creating market-based approaches such as emissions trading. Energy security has recently become an important policy driver. In developed countries, reliance on only a few suppliers, and threats of natural disasters, terrorist attacks and future uncertainty about imported energy supplies add to the concerns. For developing countries lack of security and higher world energy prices constrain endeavors to accelerate access to modern energy services that would help to decrease poverty, improve health, increase productivity, enhance competition and thus improve their economies [23–28].

3. Water potential and dams in Turkey

The amount of precipitation in any particular region usually varies from year to year but, over a long period, the average remains relatively constant. Turkey averages about 643 mm of precipitation annually, but the distribution is quite uneven. The range is from less than 250 mm in the inland areas of central Anatolia to more than 3000 mm in the northeastern Black Sea coastal region. Autumn marks the start of the rainy season, which continues until late spring on the western and southeastern coasts; whereas the Black Sea coast receives rain throughout the year [7].

This average annual precipitation corresponds to an average of 501 km^3 (501 billion m^3) of water per year. While 274 km^3 of this quantity returns to the atmosphere through evaporation–transpiration, 69 km^3 feeds the aquifers through infiltration from the surface. Thus the average annual surface water potential is 186 km^3, of which 158 km^3 comes from surface run-off and 28 km^3 of groundwater feeds the rivers. With a surface run-off of 7 km^3 volume coming from the neighboring countries, the total surface run-off within the country reaches 193 km^3. However,

Table 3
Developments in production and consumption of energy between 2000 and 2005, in Turkey.

	2000	2001	2002	2003	2004	2005
Primary energy production (TTOE)	27,621	26,159	24,884	23,779	24,170	28,020
Primary energy consumption (TTOE)	81,193	75,883	78,322	83,936	87,778	94,300
Consumption per-capita (KOE)	1,204	1111	1131	1196	1234	1249
Electricity installed capacity (MW)	27,264	28,332	31,846	35,587	36,824	39,596
Thermal (MW)	16,070	16,640	19,586	22,990	24,160	26,481
Hydraulic (MW)	11,194	11,692	12,260	12,597	12,664	13,115
Electricity production (GWh)	124,922	122,725	129,400	140,580	150,698	165,346
Thermal (GWh)	94,011	98,653	95,668	105,190	104,556	124,321
Hydraulic (GWh)	30,912	24,072	33,732	35,390	46,142	41,025
Electricity import (GWh)	3786	4579	3588	1158	464	636
Electricity export (GWh)	413	433	435	587	1144	1812
Total consumption (GWh)	128,295	126,872	132,553	141,151	150,018	
Consumption per-capita (kWh)	1903	1857	1914	2011	2109	2240

Source: Refs. [29,31].

from the economic and technical points of view, the average exploitable water potential of the country is 110 km^3 per year [7,32,33].

In view of the considerable variation in run-off in terms of seasons, years and regions, it is absolutely necessary for the major rivers in Turkey to have water storage facilities, to allow for the use of the water when it is necessary. Consequently, priority has always been given to the construction of water storage facilities. Significant progress has taken place in the construction of dams throughout the 48 years that have elapsed since the establishment of the State Hydraulic Works (DSI) [8].

Rivers weave in and out of our lives, providing innumerable benefits to communities across the world. In our planet, the rivers for drinking water, irrigation, aquatic habitat, fisheries, energy, navigation, recreation and simply the natural beauty they bring to our landscapes. Humans have been building dams and other river blockages to harness and control water for centuries, attempting to secure its benefits for human use. On the other hand, by design, dams alter the natural flow regime, and with it virtually every aspect of a river ecosystem, including water quality, sediment transport and deposition, fish migrations and reproduction, and riparian and floodplain habitat and the organisms that rely on this habitat. Dams also require ongoing maintenance. For example, reservoirs in sediment-laden streams lose storage capacity as silt accumulates in the reservoir. In arid climates reservoirs also experience a high rate of water loss to evaporation [34].

The Southeastern Anatolia Project (GAP) project originally planned by the State Hydraulic Works is a combination of 12 major projects primarily for irrigation and hydroelectric generation. The project includes the construction of 22 dams and 19 hydroelectric power plants on the Euphrates and the Tigris rivers and their tributaries. It is planned that upon completion, over 1.8 million ha of land will be irrigated and 27 billion kWh hydroelectric energy will be generated annually.

The GAP area is rich in water resources. The Euphrates and Tigris rivers represent over 28% of the country's water supply by rivers, and the economically irrigable areas in the region make up 20% of those for the whole Turkey. The development of the region was originally planned as relating to its water resources, which were later combined in a comprehensive water and land resources development package. For this purpose, total 12 groups of projects were planned on the Euphrates and Tigris rivers and their branches by the General Directorate of State Hydraulic Works [35,36] as given in Table 4.

The package included the construction of 22 dams, 19 hydroelectric power plants and the irrigation facilities to serve 1.7 million ha of land. The total installed capacity of the power plants is 7500 MW with an annual production of over 27 billion kWh. There are two main basin projects: the Euphrates and the Tigris basin projects. The Euphrates basin projects has 5304 MW installed capacity, will generate 20 billion kWh of energy and will irrigate 1 million ha of land. 14 dams and 11 hydroelectric power plants are planned for this basin. The Tigris basin projects have 2172 MW installed capacity, will generate 7 billion kWh of electric energy and will irrigate 700 000 ha of land area. Eight dams and eight hydroelectric power plants are planned for this basin [37].

The Lower Euphrates Project is one of the GAP schemes on the Euphrates river and consists of Atatürk Dam and Hydroelectric power plant (HEPP), Şanlıurfa tunnels and hydroelectric power plant, Şanlıurfa-Harran irrigation, Mardin-Ceylanpınar irrigation, Siverek-Hilvan pumped irrigation. Main public investments in this project have been completed. Atatürk dam was completed in 1990 which the sixth largest-volume dam (48.7 billion m^3) in the world. Type of dam is rock packed with 169 m high from river bed and 1664 m crest long. Body packed volume of the dam is 84.5 million m^3. Water reaches from the Atatürk dam to Şanlıurfa-Harran plains via the Şanlıurfa tunnels system, which consists of two parallel tunnels each 26.4 km long and 7.62 m in diameter. This irrigation tunnel system is the largest of its kind and it has numerous irrigation networks, canal systems constitute the physical groundwork in water resources. Tunnels were completed in 1997, and irrigation is now practised in a 250 000 ha; (total is 476 000 ha) [35,36].

4. Hydropower as a renewable and sustainable energy source

Top Ten Reasons to Include Hydropower in All Renewable Energy Initiatives. In the last 2 years, representatives from more than 170 countries have reached a consensus by declaring all hydropower to be renewable and worthy of international support, first at the world summit on sustainable development in Johannesburg (2002), and again at the 3rd world water forum in Kyoto (2003). Some of the supporting evidence for this is summarized below [4–6].

- *Hydropower is a renewable source of energy*: hydropower uses the energy of flowing water, without depleting it, to produce electricity; therefore, all hydropower projects – small or large, run-of-river or storage – meet the definition of renewable.
- *Hydropower supports the development of other renewables*: hydropower facilities with reservoirs offer unique operational flexibility in that they can respond immediately to fluctuating demand for electricity. Hydropower's flexibility and storage capacity make it the most efficient and cost-effective way to support the deployment of intermittent renewables such as wind or solar power [5].
- *Hydropower fosters energy security and price stability*: river water is a domestic resource and, unlike fuel or natural gas, it is not

Table 4
Water and land resources development projects in the GAP region, in Turkey.

Project	Capacity (MW)	Production (GW)	Irrigation area (ha)	Present stage
Karakaya dam and HEPP	1800	7354		OP
Lower Euphrates project				
Atatürk Dam and HEPP	2400	8900		OP
Şanlıurfa HEPP	50	124		UC
Şanlıurfa irrigation tunnels			476,000	UC
Siverek-Hilvan pumped irrigation			160,000	E
Bozova pumped irrigation			70,000	E
Border Euphrates project				
Birecik dam and HEPP	852	3168		UC
Karkamış dam and HEPP	180	652		DD
Suruç-Baziki plain irrigation			146,500	E
Adıyaman-Kahta project				
Adıyaman-Göksu dam and irrigation	7	43	71,600	FS
Çamgazi dam and irrigation			7430	UC
Koçalı dam and HEPP	40	120	21,605	MP
Büyükçay dam, HEPP and irrigation	30	84	12,322	MP
Kahta dam and HEPP	75	171		MP
Pumped irrigation from Atatürk dam			29,599	MP
Gaziantep project				
Hancağız dam and irrigation			7330	OP
Kayacık dam and irrigation			14,740	UC
Pumped irrigation from Birecik dam			66,000	FS
Dicle-Kralkızı project				
Kralkızı dam and HEPP	94	146		UC
Dicle dam and HEPP	110	298		UC
Dicle right bank gravity irrigation			54,280	UC
Dicle right bank pumped irrigation			75,870	UC
Batman project				
Batman dam and HEPP	198	483		UC
Batman left bank gravity irrigation			9570	UC
Batman left bank pumped irrigation			9180	FS
Batman right bank gravity irrigation			18,600	DD
Batman-Silvan project				
Silvan dam and HEPP	150	623		MP
Kayser dam and HEPP	90	341		MP
Dicle left bank gravity irrigation			250,000	E
Garzan project				
Garzan dam and HEPP	90	315		E
Garzan irrigation			60,000	E
Ilýsu dam and HEPP	1200	3830		DD
Cizre project				
Cizre dam and HEPP	240	1208		DD
Nusaybin Cizre irrigation			89,000	E

OP: in operation; UC: under construction; E: exploration; DD: detailed design completed; FS: feasibility study; MP: master plan.
Source: Refs. [35,36].

subject to market fluctuations; moreover, hydropower is the only major renewable source of electricity, and its cost-effectiveness, efficiency, flexibility and reliability help optimize the use of thermal plants [4,6].

- *Hydropower contributes to fresh water storage*: hydropower reservoirs collect rainwater, which can then be used for drinking or irrigation. By storing water, they protect aquifers from depletion and reduce our vulnerability to floods and droughts.
- *Hydropower improves electric grid stability and reliability*: the management of electricity grids depends upon fast, flexible generation sources to meet peak power demands, maintain level system voltages and quickly restore service after a blackout. Electricity generated from hydropower can be placed on the grid faster than any other energy source. Hydropower's ability to go from zero power to maximum output rapidly and predictably makes it exceptionally good at meeting changing loads and providing ancillary electrical services that maintain the balance between electricity supply and demand [9,10].
- *Hydropower helps fight climate change*: the life-cycle of hydropower produces very small amounts of greenhouse gases (GHGs). By offsetting GHG emissions from gas, coal and oil fired power plants, hydropower can help slow global warming. Although only 33% of potential hydro resources have been developed, hydropower currently avoids burning 4.4 million barrels of oil equivalent daily, worldwide.
- *Hydropower improves the air we breathe*: hydropower plants produce no air pollutants. Very often, they replace fossil-fired generation, thereby reducing acid rain and smog. Moreover, hydropower projects do not generate any toxic by-products.
- *Hydropower makes a significant contribution to development*: hydropower facilities bring electricity, roads, industry and commerce to communities, thereby developing the economy, improving access to health and education, and enhancing the quality of life. Hydropower is a technology that has been known and proven for over a century. Its impacts are well understood and manageable through mitigation and enhancement mea-

sures. It offers vast potential and is available where development is most needed.

- *Hydropower means clean, affordable power for today and tomorrow*: with an average life span of 50–100 years, hydropower projects are long-term investments that can benefit several generations. They can easily be upgraded to incorporate the latest technologies and have very low operation and maintenance costs.
- *Hydropower is a key tool for sustainable development*: hydropower projects that are developed and operated in an economically viable, environmentally sound and socially responsible manner represent sustainable development at its best, i.e. "development that meets the needs of the people today without compromising the ability of future generations to meet their own needs." (World Commission on Environment and Development, 1987) [4–6].

5. Hydropower potential in Turkey

Turkey has important hydropower potential. Therefore, Turkey has rigorous plans for the development of its substantial hydropower potential. Approximately 5500 MW of hydropower capacity is under construction, the largest schemes being Deriner Dam in the north of the country (680 MW) and Berke Dam in the southeast (520 MW). In Turkey, 566 hydropower projects by DSI (State Hydraulic Works) [38] have been identified for development in total, 130 are already in operation, 31 are under construction, and 405 (with a capacity of 19 951 MW) are planned. Table 5 shows development of irrigation, hydropower and water supply in Turkey up to 2030 [38] and Table 6 shows the renewable energy supply and projections for future in Turkey, respectively [38–42].

The distribution of hydroelectric power potential in Turkey is expected that the total hydro installed capacity will be almost 36 000 MW, by 2020. Thus, within this framework, it is also expected that the GAP (Southeastern Anatolian Project) will comprise 22 dams and 19 hydroelectric plants and a total generation of about 27 TWh/year, and the irrigation of an area of 1 785 050 ha will be realized. The GAP is an integrated, multi-sectorial development project, and covers many sectors such as agriculture, industry, transportation, water sports, etc. Dams are necessary not only for irrigation and hydropower, but also for the domestic water supply in large cities. The hydraulic projects often improve environmental conditions, providing wetlands and various new developments in the vicinity of the reservoir [43,44].

By the year 2010, Turkey is planning to exploit two-third of its hydropower potential, aiming to increase hydro-production to about 75 000 GWh/year. By 2020 this will rise to 100 000 GWh/year, and by 2030 it could be 140 000 GWh/year [37,38]. On the other hand, there are 436 sites available for hydroelectric plant construction, distributed on 26 main river zones. The total gross potential and total energy production capacity of these sites are nearly 50 GW and 112 TWh/year, respectively. As an average, 30% of the total gross potential may be economically exploitable. At present, only about 18% of the total hydroelectric power potential is exploited. The national development plan aims to harvest all of the hydroelectric potential by 2010 [45–47].

Table 5
Development of irrigation, hydropower and water supply in Turkey.

	In operation (2005)	Ultimate goals (2030)	Development rates (%)
Irrigation	4.9 million ha	8.5 million ha	58
Hydroelectric energy	45.3 billion kWh	127.3 billion kWh	36
Water supply	10.5 billion m^3	38.5 billion m^3	27

Source: Ref. [38].

Table 6
Present and potential of hydroelectric power in Turkey.

	Number of power stations	Total installed capacity (MW)	Proven production (GWh/year)	Total annual production (GWh/year)
Present hydropower plants				
In production > 10 MW	74	193	287	722
In production < 10 MW	68	12,595	33,273	45,208
Under construction > 10 MW	8	45	151	228
Under construction < 10 MW	32	3152	6207	10,290
Present total	182	15,985	39,918	56,448
Future possible potential				
>5 MW	164	366	571	1848
5–10 MW	82	610	897	2587
10–50 MW	187	4727	9234	18,959
50–100 MW	51	3692	7734	13,001
100–250 MW	37	5815	11,824	19,308
240–500 MW	10	3250	5620	10,688
500–1000 MW	2	1053	2054	3173
1000 < MW	1	1200	2459	3833
Future total	534	20,713	40,393	73,398
Total	716	36,698	80,311	129,846

Source: Ref. [38].

6. Conclusion

Turkey is an energy importing nation with more than 70% of energy requirements met by imported expensive fuels. Air pollution is becoming a significant environmental concern in the country. In this regard, hydropower and other renewable energy sources are becoming attractive solution for clean and sustainable energy future of Turkey.

Turkey's abundant hydropower potential (both large dams and small hydropower) is among the highest in Europe, but only one-third of this capacity is utilized. Turkey's total hydropower capacity is estimated at 433 TWh/year. Also the economically feasible hydroelectric potential is estimated at about 125 TWh/year and the installed capacity is 35 000 MW/year. Hydropower installed capacity increased by 5.0% per year from 1990 to 2005. Hydropower contributed 21% of total renewable energy supply and 2.7% of total primary energy supply in 2005. As a result, hydropower especially small hydropower is very important for Turkey to generate electricity and supply water.

As regards small hydro plants, according to the hydrological and topographical conditions of the country, it is estimated that there is considerable amount of SHP potential in Turkey. Since the investment costs of small plants are high when they are implemented individually, it would be useful to standardize the manufacturing of electromechanical equipment and build them in groups, to decrease transmission and distribution costs. In view of the privatization policy, strategies oriented towards technical aspects, as well as legislative and administrative issues, must be clarified so as to mobilize and accelerate small hydro development in Turkey [7,48,49].

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